Resolving Long-Term Change in Polynesian Marine Fisheries

MELINDA S. ALLEN

THE OFTEN DRAMATIC IMPACT OF EARLY POLYNESIAN settlers on island flora and fauna has now been amply demonstrated. Native birds in particular were devastated by the arrival of people and their commensal animals (e.g., Steadman 1991, 1995). Clearance for gardens brought further changes with vast lowland areas being transformed from native forest to open fields, secondary shrub, and in some places, entirely anthropogenic aboricultural systems (e.g., Kirch and Yen 1982; Spriggs 1986). Coastal-nesting species, such as turtles and seals, were also adversely affected, both by direct hunting and otherwise (e.g., Dye and Steadman 1990). Early settlers apparently ate well, with some authors even suggesting that Polynesian colonists were driven to explore by the prospects of rich and varied culinary delights. But what happened when these resources were depleted? Our attention has focused more on the demise of native species and landscape change, and less on the long-term impact these losses had on Pacific island economies.

One expectation is that the disappearance of accessible and abundant protein resources would have led to an increased dependence on less desirable and more costly ones, as for example fish and shellfish (see Broughton 1994, 1999; Nagaoka 2000). However, on at least one central Polynesian island, Aitutaki in the Southern Cook Islands, the situation is more complex, with many factors apparently contributing to subsistence change. Most striking in the Aitutaki case is a trend that runs counter to both theoretical expectations and popular notions about life on tropical Pacific islands, namely that fishing became less, not more, important over time. Notably, the decreasing role for fishing seen on Aitutaki may be echoed elsewhere in the region. I consider why this occurred and the relationships between fishing, the overall subsistence economy, and other related cultural processes. This involves reviewing changes in fishing technologies, catch composition, habitat use, and the possibility of resource depression or over-harvesting. I also discuss the contribution of a new high-precision technique for fish identification, mtDNA analysis, and outline the potential of a second, stable isotope analysis, which may also improve our understanding of Pacific agricultural histories and animal husbandry practices. While the issues are not entirely resolved,

Melinda Allen is Senior Lecturer in Anthropology in the Department of Anthropology, University of Auckland, New Zealand.

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my aim is to demonstrate the value of a multifaceted approach with the potential for application to other contexts.

The Aitutaki archaeological assemblages provide an ideal test case for evaluating long-term developments in prehistoric Polynesian fisheries. As a whole, the collection is one of the region's largest archaeofish assemblages, with more than 15,000 identified specimens and many more thousands of unidentified bones (Allen 1992*a*). The large number of specimens is in part related to the use of fine mesh (1/8 in, 3.2 mm) screens but also reflects exceptional preservation. The materials derive from four localities. Three of these are on the Aitutaki mainland and most likely reflect relatively permanent settlements; the earliest site dates to at least 1000 years B.P. A fourth site, a rockshelter on the offshore islet of Moturakau, represents 700 years of intermittent use. The sites are all stratified and well dated by 27 radiocarbon determinations (Allen 1994), the oldest having passed the stringent requirements of "chronometric hygiene" (Spriggs and Anderson 1993:209). The geomorphic context of the mainland sites also has been well studied (Allen 1992*a*, 1998). In addition to my own research, the Aitutaki collections have been fruitful ground for subsequent studies, including those of Nagaoka (1992, 1994) who undertook a detailed methodological analysis of the Moturakau archaeofish remains and Coleman (1999) who analyzed the taphonomy and potential dietary contribution of Pacific rat *(Rattus exulans)*. As a whole, the characteristics outlined above make these assemblages particularly useful for resolving questions of how and why local fisheries changed, and for the application of new approaches and technologies.

BACKGROUND TO SITES

Aitutaki Island is an almost-atoll (after Stoddart and Gibbs 1975) (Fig. 1). It has a 16 km^2 volcanic mainland, a moderate size lagoon, several coral islets along its perimeter, and two volcanic islets within the lagoon, Moturakau and Rapota (see Allen 1992*a*; Stoddart and Gibbs 1975 for further details on the local environment). Allen (1992*a*) identified four marine habitats that were important food resource areas in the past: the inshore reef platform; the relatively shallow lagoon (generally less than 10 m in depth); the outer reef platform, which encircles the lagoon; and the outer reef edge, which fronts the open sea.

Three of the four sites that provided the archaeofish assemblages are located on the volcanic mainland (Fig. 1): Ureia (AIT-10), Hosea (AIT-50), and Aretai (AIT-49). They occur on a low-lying coastal flat of approximately 250 to 400 m in width on the western side of the island. This sandy flat probably formed within the last 1500 years (Allen 1998). Human settlement had occurred by at least 1000 B.P., and probably a few centuries earlier. These three sites provide a 1000-year record of human occupation. At each locality two or more cultural layers are found, alternating with storm deposits. While deposition of these storm units may have removed some portion of each underlying cultural layer, they also provided some measure of protection against other kinds of post-depositional disturbances. Geomorphic study of this coast indicates that terrigenous sedimentation only became significant here in the post-European era and has had little effect on the localities discussed herein (Allen 1998). All three sites are thought to be residential home bases, as detailed in Allen (1992*a*), but the best sampled and most convinc-

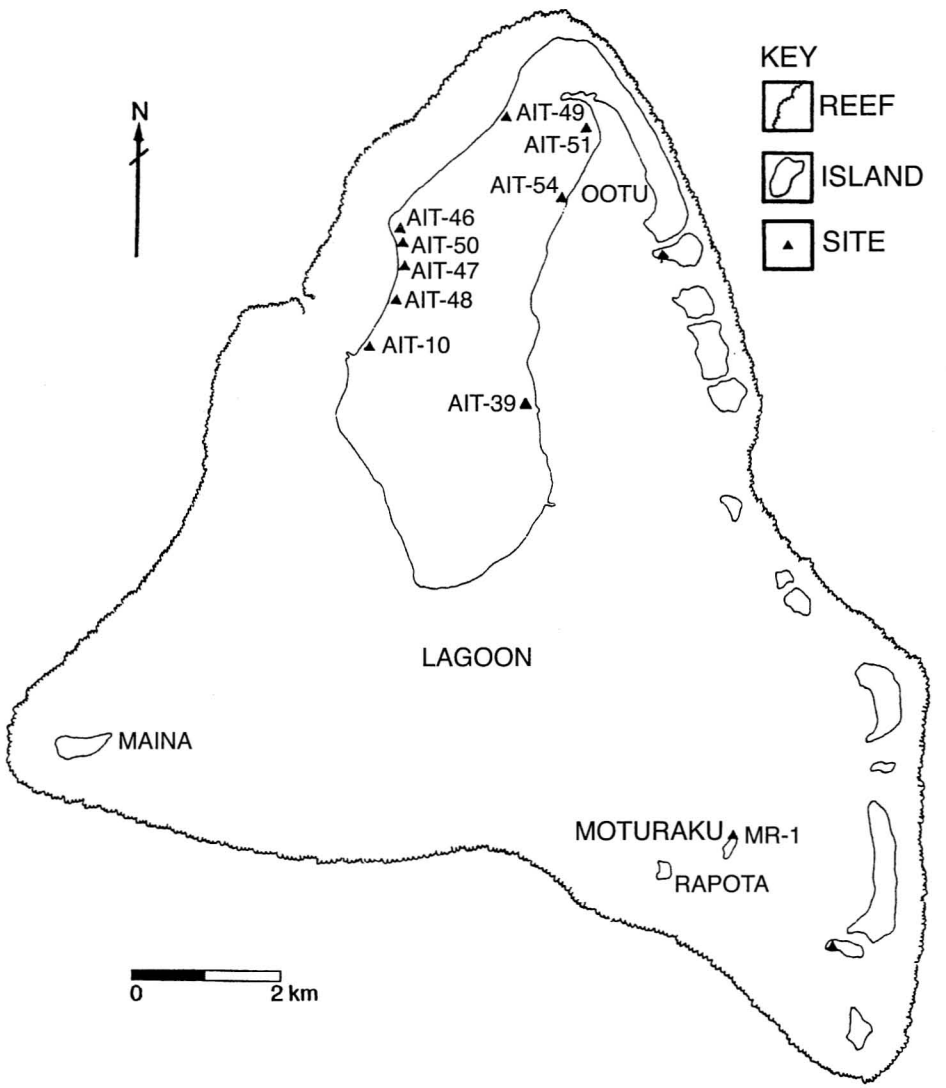

Fig. 1. Aitutaki Island and location of major excavations.

ing record comes from Ureia. Here Bellwood (1978), and later Allen (1992*a*), recorded earth ovens, smaller fire pit features, pavements, and post molds, all suggestive of relatively permanent living areas.

The fourth site (MR-1) is found on the offshore islet of Moturakau, which lies at the southern end of the lagoon (Fig. 1). The deposit here also is stratified with a 700-year record of cultural activities. In addition to being situated near to the atoll reef platform and the outer reef edge, both which were important fish and shellfish habitats, the islet itself has blocks of fine-grained basalt that were used for adze manufacture (Allen 1992*a*; Allen and Johnson 1997). The nearby islet of Rapota also offers fine-grained basalt. However, what probably attracted the pre-

Fig. 2. Moturakau rockshelter (MR-1).

historic inhabitants of Aitutaki to Moturakau was the islet's small rockshelter, a rarity in this near-atoll environment (Fig. 2). This shelter has preserved an exceptional record of fishing, with more than 11,000 identifiable fish bones coming from a 2 m^2 sample of the 16 m^2 that were excavated (Allen 1992*a*; Allen and Schubel 1990). Varied lines of evidence indicate (see Allen 1992*a*:260–277) that in contrast to the mainland sites, Moturakau rockshelter was a specialized and temporary living area, one used in conjunction with both marine harvesting activities and basalt adze manufacture.

TEMPORAL TRENDS IN MARINE EXPLOITATION

Detailed analysis of the Aitutaki materials has revealed four significant trends in the prehistoric marine fisheries (Allen 1992*b*, 1996), including changes in fishing technologies, catch composition, fishing habitats, and a shift in the relative importance of fishing overall. Fishing technologies must often be inferred from fish remains themselves, given that most traditional fishing gear is made of organic materials and does not preserve. On Aitutaki, our understanding of past technologies is enhanced by a collection of archaeological fishhooks, augmented by ethnographic accounts of traditional fishing methods. The fishhooks are concentrated in the earliest stratigraphic contexts, with the largest collection coming from Moturakau rockshelter (Fig. 3). Early in the rockshelter sequence, around A.D. 1300, there is evidence for both on-site manufacture and use of fishhooks. Most of these hooks were made from pearl shell or black-lip pearl oyster (*Pinctada margaritifera* L.), but a small number of specimens were made from setose turban

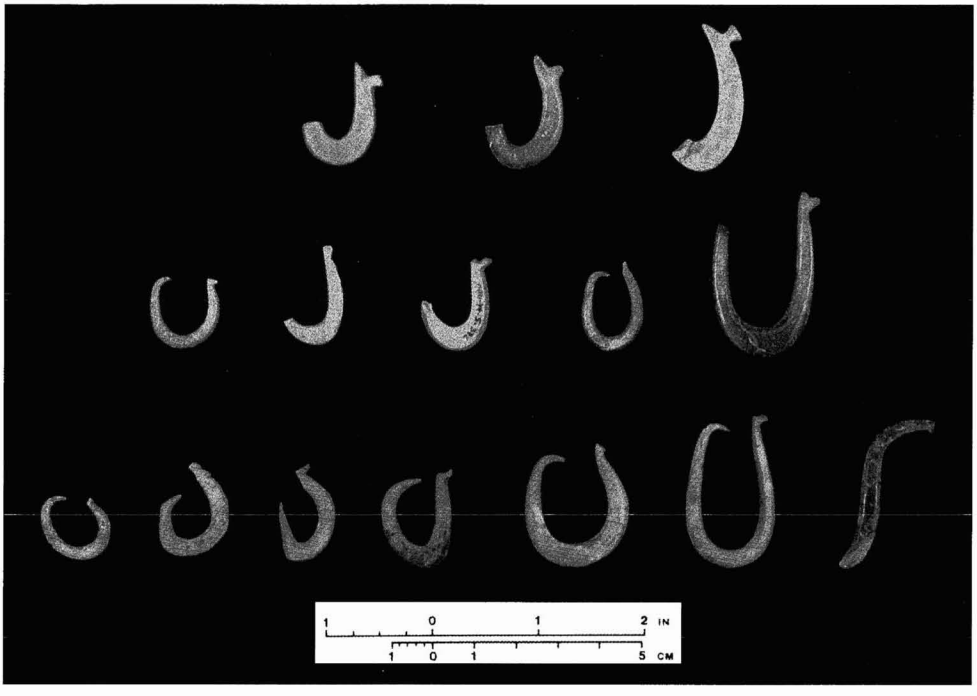

Fig. 3. Examples of Aitutaki shell fishhooks: lower row—early hooks in pearlshell, middle row—mid-sequence examples, and top row—late turban shell hooks.

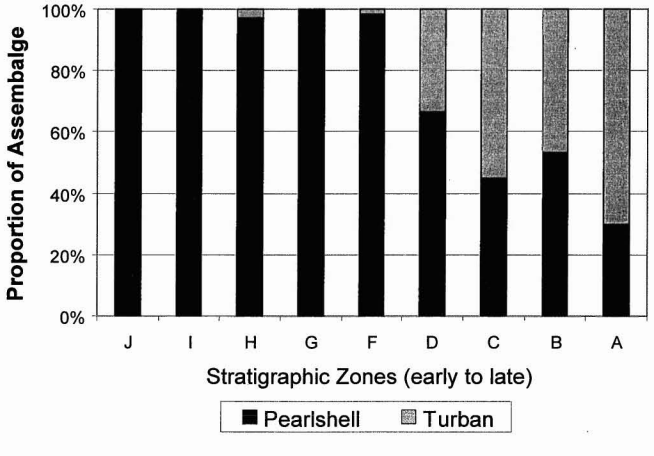

Fig. 4. Moturakau fishhooks, preforms, and blanks by raw material type, from early Zone J to most recent Zone A. Zone E is sterile.

shell (*Turbo setosus* Gm.) (Fig. 4). Around A.D. 1450 to 1550 (Zone D), pearlshell hooks decline, along with pearlshell fishhook preforms and blanks. At the same time, there is an increase in the use of turban shell, although pearlshell hooks continue to dominate the assemblage. Then, in the last few centuries before European contact (ca. A.D. 1650), shell hooks and evidence for their manufacture altogether disappear from the record.

The reasons underlying the loss of shell hooks are not well understood. One possibility is that removal of forest from the volcanic mainland initiated erosion on the eastern coast of the island, which in turn led to deterioration of the lagoon's pearlshell habitat (Allen 1992*a*). In this regard, today there is little native forest left on the mainland (Stoddart and Gibbs 1975), and portions of the eastern coast are covered with terrestrially derived mud. Pearlshell also declines elsewhere in the Cook Islands at around the same time (Kirch et al. 1995). On Mangaia, where pearlshell does not occur naturally, Weisler (1993) argues that its source was the Northern Cook Islands and its disappearance reflects a breakdown in regional exchange networks. While the cause of pearlshell declines remains unresolved, the end result on Aitutaki was the abandonment of shell fishhooks.

The Moturakau evidence suggests that for a time, there was experimentation with turban, and possibly even other shell taxa, as an alternative raw material (Allen 1992*b*). But the turban hooks are all of the jabbing variety, rather than the varied and curvaceous pearlshell forms executed in earlier times, perhaps indicating material constraints. Moreover, use of turban shell was accompanied by more manufacturing failures, further suggesting it was a difficult material to work with. These findings are not unexpected given the physical characteristics of the two shells. As previously discussed elsewhere (Allen 1992*b*:186–187), pearlshell has a nacreous structure that makes it more resistant than turban shell to breakage in various dimensions, including tension, compaction, impact, and bending—differences demonstrated through engineering tests by the author, Robert Dunnell, and associates at the University of Washington. Given these considerations, the switch to turban shell was a costly one in terms of both hook production and hook use-life. By the time of Peter Buck's (1927) ethnographic study in the early 1920s, shell hooks were no longer in use and nets and weirs were the most common forms of fishing gear.

Another trend observed in the Moturakau assemblage is a weak decline in the representation of offshore and pelagic fish. The offshore zone, as defined here, includes the outer reef edge and adjacent benthic area; in contrast, the inshore zone refers to nearshore areas and the inner lagoon waters. Although there is uncertainty in assigning fish families that have both inshore and offshore representatives (see below), potential offshore taxa found in the Aitutaki collections include serranids (groupers and rockcods), lutjanids (snappers), carangids (jacks and trevallies), cirrhitids (hawkfishes), and sphyraenids (barracudas). Pelagic taxa represented on Moturakau include the scombrids (tunas, bonitos, and mackerels). Most problematic in terms of habitat assignment are the serranids, which comprise about 40 percent of the total Moturakau assemblage.

Given their abundance, the habitat assignment of serranids has had a serious impact on interpretations of the relative importance of inshore versus offshore fishing (see discussion in Allen 1992*a*). If serranids are included with the offshore fish, then fishing along the outer reef and beyond contributed 62 to 45 percent of the Moturakau fish remains (Fig. 5). If they are not, then offshore fishing was a more minor activity represented by only 18 to 11 percent of the fish remains (Fig. 6). While Rolett (1998) uses size to assign Marquesan serranid remains to one habitat category or the other, in the Aitutaki case the specimens are relatively uniform in size and this approach cannot be used with any confidence. Given the proximity of the Moturakau site to the outer reef edge, and considering that fish-

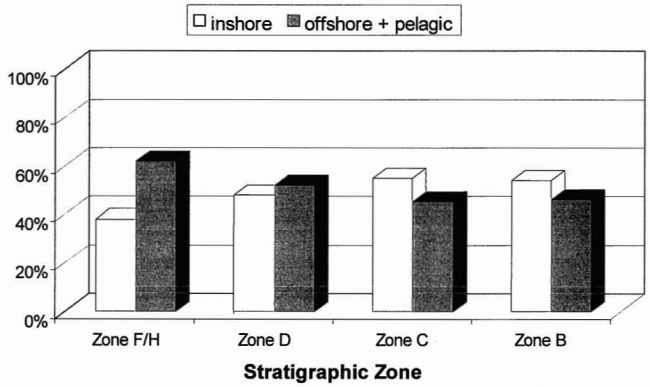

Fig. 5. Moturakau fish remains by habitat, serranids included with offshore fish, from early Zone F/H to recent Zone B.

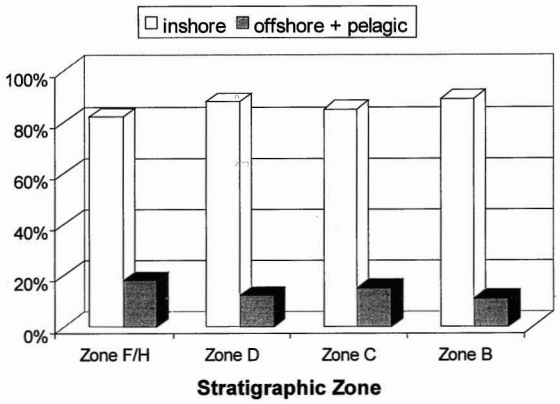

Fig. 6. Moturakau fish remains by habitat, serranids included with inshore fish, from early Zone F/H to recent Zone B.

ing was a key activity during its occupation, an argument could be made that the rockshelter serranids are most likely offshore taxa; genetic analysis, however, suggests otherwise (see below). Regardless of where the serranids are placed, offshore fishing declines somewhat over time and pelagic fishing is never important. By way of example, lutjanids decline from 9 percent (228 NISP) in the earliest layer to 2 percent (16 NISP) in Zone B of the Moturakau shelter.

Perhaps the most interesting trend seen on Moturakau, and at all three mainland sites, is a decline in fish remains generally (Figs. 7, 8). Importantly, the sedimentary contexts of three mainland sites and the offshore islet are quite different suggesting the declines do not represent changing sedimentary regimes. Moreover, repetition of this trend across multiple mainland sites is seen as strong evidence of changing rates of fish bone deposition. The decline is most dramatic at the special purpose site of Moturakau, where the density of fish bone drops from a high of 6046 NISP per m^3 in the earliest stratigraphic zones to a low of 563 NISP per m^3 in the most recent (probably historic) zone. The most significant decline takes place after the sixteenth century, coincident with the decline in pearl shell fishhooks. By way of comparison, other vertebrate remains vary over time, with some taxa increasing (e.g., *Rattus exulans*), and others remaining stable

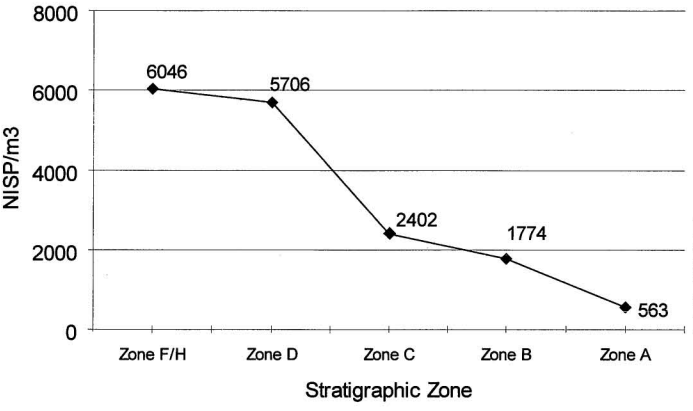

Fig. 7. Changing patterns of fish bone density (NISP/m^3) in the Moturakau rockshelter, from early Zone F/H to recent Zone B.

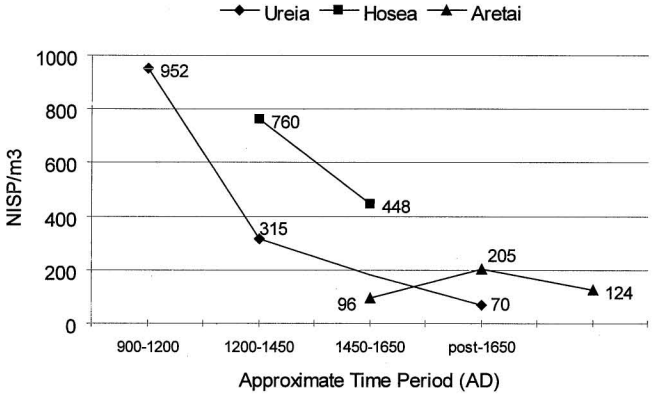

Fig. 8. Changing patterns of fish bone density (NISP/m^3) in the three mainland sites; approximate time periods based on Allen 1994.

(e.g., domestic chicken). As a whole, nonfish vertebrate remains increase markedly from Zone F/H to Zone C and then decline somewhat thereafter (see Allen 1992*a*, Table 8.22).

On the mainland, the decline in fish bone density is greatest at the longest occupied site of Ureia, where it drops from 952 NISP per m^3 to 70 NISP per m^3. In contrast, chicken and dog (and nonfish vertebrates as a whole) increase over time (Allen 1992*a*, Table 8.20). Moreover, the available evidence suggests that the rate of sediment accumulation at Ureia slows over time (Allen 1992*a*:144, 1998). At the slightly later site of Hosea (AIT-50), the decline in fish remains is similar, with the earlier cultural layer dating to ca. A.D. 1300 and the later one to A.D. 1600. At the Aretai site (AIT-49), where both prehistoric layers date to the period of ca. A.D. 1400 to 1600, the density of fish bone is relatively stable, but markedly lower than at the other three sites.

In light of terrestrial protein losses seen elsewhere in the region in association with long-term settlement, we might expect that marine exploitation would increase not decrease over time. The greater declines at the longer occupied Ureia site, however, raise the possibility that over-harvesting or resource depression could have played a causal role in decisions to reduce fishing. To evaluate this possibility, I applied a model of resource depression developed by Broughton (1994, 1999; see also Butler 2001; Nagaoka 2000) to the Aitutaki assemblages

(Allen n.d.). The model also has similarities to an approach used some time ago by Anderson (1981) to evaluate human impact on shellfish resources in a coastal New Zealand setting.

EVALUATING HUMAN IMPACT ON FISH RESOURCES

The resource depression model of Broughton derives from the more general prey choice model of foraging theory. The core thesis is that the most efficient predator behavior is to take prey in relation to their return rates. Broughton (1999) argues that a useful measure of return rate is prey body size, although return rates may be lower for exceptionally large prey (e.g., whales) or higher for small prey that can be mass harvested (e.g., sardines). In general, however, we can expect that when available, large-bodied prey will be taken preferentially over small-bodied prey. Resource depression, or reductions in the abundance of preferred prey, occurs when people use resources at an unsustainable rate. This situation may arise under varied conditions, including increases in the size of the predator population, when predator mobility is limited, or when social demands (tribute, ritual activity, etc.) lead to increased harvesting. Any one or all three conditions could have operated on the small island of Aitutaki.

To monitor changes in prey types, Broughton developed a series of indices (see also Butler 2001). The one below is an index of the ratio of large inshore fish to all inshore fish:

$$\frac{\sum \text{NISP large inshore taxa}}{\sum \text{NISP large inshore taxa} + \sum \text{NISP small inshore taxa}}$$

The NISP values used in this (and other indices herein) are based on the five diagnostic mouth elements most commonly used in Pacific fish identifications (i.e., premaxilla, dentary, maxilla, quadrate, and articular). In using these ratios, the higher the value (i.e., the closer to 1.0), the greater the contribution of large-bodied prey to the diet. The large inshore fish category comprises taxa that typically obtain body lengths in excess of 35 cm (following Butler 2001), including parrotfish (Scaridae), eels (Muraenidae), bonefish (Albulidae), left-eye flounders (Bothidae), and emperors (Lethrinidae) (Tables 1, 2). Other large-bodied prey that could have originated in offshore areas, such as the serranids and carangids, were not included in the large inshore fish group. Among the more common smaller fish are wrasses (Labridae), goatfish (Mullidae), surgeonfish (Acanthuridae), squirrelfish and soldierfish (Holocentridae), triggerfish (Balistidae), and porcupinefish (Diodontidae). Notably some of these taxa also have large representatives, highlighting the problem of family level identifications.

The indices show that at the Ureia site, large-bodied or high-ranked prey decrease over time (Table 1). In general the pattern is consistent with expectations derived from the resource depression model. The composition of the Ureia assemblages also hints at shifts in habitat use. While inshore fish predominate throughout, they constitute a larger proportion of the overall assemblage in the earliest strata. Over time, offshore fish increase but only marginally (e.g., carangids from 2 percent to 7 percent). The evidence is consistent with the idea that nearshore areas were gradually overfished, with the result that areas adjacent to the site became less profitable over time. By Zone C, fishermen may have been

TABLE 1. UREIA (AIT-10) FISH TAXA (NISP[a]) AND LARGE FISH INDICES BY STRATIGRAPHIC ZONE

	STRATIGRAPHIC ZONE			
TAXON	ZONE G	ZONE E	ZONE C	TOTAL NISP
Inshore taxa—large				
Albulidae	1	+[b]	0	1
Bothidae	1	0	0	1
Lethrinidae	2	5	3	10
Muraenidae	+	1	1	2
Scaridae	136	78	17	231
Scorpaenidae	0	0	1	1
Subtotal	140	84	22	246
Inshore taxa—small				
Acanthuridae	4	3	2	9
Aulostomidae	0	+	0	+
Balistidae	+	3	1	4
Diodontidae	+	1	1	2
Holocentridae	14	17	1	32
Labridae	11	15	1	27
Mullidae	21	13	4	38
Ostraciidae	+	+	1	1
Serranidae	86	85	35	206
Siganidae	0	+	0	+
Tetradontidae	0	1	2	3
Subtotal	136	138	48	322
Total inshore fish	276	222	70	568
Large inshore fish index	0.51	0.38	0.31	
Offshore taxa—large & x-large				
Elasmobranchii	+	+	+	+
Ray	0	0	1	1
Belonidae	0	2	0	2
Carangidae	5	10	6	21
Lutjanidae	15	11	4	30
Subtotal	20	23	11	54
Offshore taxa—small				
Cirrhitidae	1	0	0	1
Total offshore + pelagic fish	21	23	11	55
Total no. of taxa	17	19	16	23
Total NISP	297	245	81	623

[a] NISP abundances based on five diagnostic mouth elements.
[b] + indicates taxon present but not represented by diagnostic mouth elements.

moving to more distant localities, where they encountered offshore taxa somewhat more frequently.

These results could explain declines in fishing overall but to consider the issue further, I also applied the resource depression model to the Moturakau assemblage. In contrast to Ureia, expectations of the resource depression model are not met here. Application of the large inshore fish index revealed an increase in large-bodied fish over time, a trend driven largely by an increase in parrotfish (Table 2). Perhaps the most important trend on Moturakau is a decline in a few groups of offshore fish, such as the lutjanids and carangids. In brief, resource depression is

TABLE 2. MOTURAKAU FISH TAXA (NISP[a]) AND LARGE FISH INDICES BY STRATIGRAPHIC ZONE

TAXON	STRATIGRAPHIC ZONE				TOTAL NISP
	ZONE F/H	ZONE D	ZONE C	ZONE B	
Inshore taxa—large					
Albulidae	8	6	3	12	29
Bothidae	29	15	8	15	67
Congridae	0	3	0	1	4
Kyphosidae	10	4	0	3	17
Lethrinidae	25	16	6	8	55
Mugilidae	3	2	1	1	7
Muraenidae	36	63	36	78	213
Scaridae	282	205	127	145	759
Subtotal	393	314	181	263	1151
Inshore taxa—small					
Acanthuridae	51	19	8	6	84
Apogonidae	2	1	0	0	3
Aulostomidae	17	4	10	12	43
Balistidae	33	39	14	8	94
Diodontidae	5	4	+[b]	15	24
Holocentridae	71	43	16	25	155
Labridae	185	110	33	26	354
Mullidae	118	104	48	36	306
Ostraciidae	1	+	+	+	1
Polynemidae	0	0	0	1	1
Pomacentridae	12	5	2	2	21
Serranidae	1076	567	186	268	2097
Siganidae	3	1	1	1	6
Tetradontidae	19	23	23	21	86
Subtotal	1593	920	341	421	3275
Total inshore fish	1986	1234	522	684	4426
Large inshore fish index	0.20	0.34	0.35	0.39	
Offshore taxa—large & x-large					
Elasmobranchii	5	4	3	5	17
Ray	0	0	0	1	1
Belonidae	91	9	24	5	129
Carangidae	75	27	22	48	172
Lutjanidae	228	89	18	16	351
Sphyraenidae	1	2	0	0	3
Subtotal	400	131	67	75	673
Offshore taxa—small					
Cirrhitidae	26	35	21	7	89
Pelagic taxa					
Scombridae	2	2	2	1	7
Total offshore + pelagic fish	428	168	90	83	769
Total no. of taxa	26	28	24	27	28
Total NISP	2414	1402	612	767	5195

[a] NISP abundances based on five diagnostic mouth elements.
[b] + indicates taxon present but not represented by diagnostic mouth elements.

not evident at Moturakau. This is not surprising, however, given that Moturakau rockshelter was a specialized and intermittently occupied campsite. The local marine environment may not have been subject to same predation pressures as the mainland settlement area. Nevertheless, there are clear changes in fishing practices which include the declining contribution of offshore fish, the loss of shell fishhooks, and declines in fish bone overall. Reduced offshore fishing could relate to the loss of pearl shell as a raw material and the greater costs of turban shell fishhooks as discussed above. The overall declines in fishing, however, are more enigmatic and require further exploration.

RESOLVING TAXONOMIC IDENTIFICATIONS

As implied by the foregoing, understanding the dynamics of marine fisheries, including changing habitat use, prey switches, and human impact, requires fine-grained information on prey types. Unfortunately, this often has not been possible in the past. The difficulties associated with specific determinations of serranid archaeofish remains, as outlined above, are common to many families of tropical Pacific fish. Polynesia has a high diversity of inshore fish, a fauna with its origins in one of the richest marine provinces in the world, the Indo-Malaysian region (Meyers 1989:10). Not unexpectedly, many families have multiple genera and species, and some even several subfamilies, the serranids being an example. Also problematic is the conservative character of many tropical Pacific fish skeletal structures. The result is that species-level variation in skeletal morphology can be minimal and even generic variation may not be apparent. When a family is relatively homogeneous in terms of species behaviors or ecologies, subfamilial identification may not be necessary for interpreting past human behaviors, as Flemming (1986) has argued for the scarids. In other cases, however, there may be a great deal of intra-family variation in diet, habitat preferences, maturation rates, etc.—with implications for when, where, and how these different species may have been captured and variation in the related costs.

In the Aitutaki case, serranids make up a large proportion (about 40 percent) of the overall fish assemblage (Tables 1, 2). Potentially, these materials could come from any one of 40-odd serranid species known from the Southern Cook Islands (G. McCormack, pers. comm. 2000) and species composition could have changed over time. Based on morphology alone, changes in species composition within the Serranidae would be archaeologically invisible, particularly within the economically important subfamily, Epinephelinae. Moreoever, assigning serranid remains to general habitat type can be difficult, as discussed in Allen (1992*a*). A novel technique with the potential to allow subfamilial variation is mtDNA analysis. Butler and Bowers (1998) attempted to resolve the specific identity of salmonid remains from the American Northwest with this technique. Similarly, Matisoo-Smith (1996) and Matisoo-Smith and Allen (2001) have shown the utility of molecular approaches in providing specific identifications of rodent remains from Pacific archaeological sites. In light of these studies, mtDNA analysis was tested as a means of resolving taxonomic variation within the Aitutaki serranids remains (Nicholls 2001; Nicholls et al. 2001).

Nicholls' (2001) work focused on the subfamily Epinephelinae (after Heemstra and Randall 1993) and in particular seven common and economically important

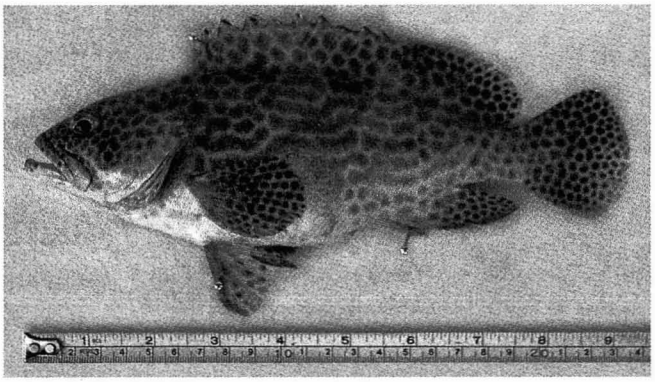

Fig. 9. *Epinephelus merra*, one of Aitutaki's most common serranids as revealed by mtDNA analysis.

species found in the Southern Cook Islands: *Epinephelus hexagonatus, E. fasciatus, E. merra, E. tauvina, E. tuamotuensis, Cephalopholis argus,* and *C. urodeta.* Sixteen Moturakau samples, selected from throughout the stratigraphic profile and from three noncontiguous excavation units, provided genetic sequence; these represent roughly 10 percent of the serranid MNI reported by Allen (1992*a*). Of these, 12 were identified as *E. merra* (dwarf spotted rock cod) (Fig. 9). The remaining four include *E. hexagonatus, E. tauvina, Cephalopholis argus,* and two unidentified taxa. Three samples from the mainland site of Ureia were also genetically identified as *E. merra.* More recent sampling is confirming the predominance of *E. merra* among the Aitutaki serranid remains.

There are several implications that follow from the finding that most of the Moturakau serranids (roughly 66 percent) derive from a single inshore species (Nicholls et al. 2001). First, it would appear that one taxon makes up the bulk of the assemblage. Second, as this taxon is an inshore species, the results indicate that offshore fishing was always a minor part of the fishing activities on Aitutaki. Third, there is no evidence for prey-switching within the serranid family over time; only four individuals of three other taxa were identified and these are not confined to any particular portion of the Moturakau sequence. Fourth, as the name implies, the dwarf spotted rock cod is a small fish, reaching a maximum length of 27.5 cm. (Randall et al. 1997:111). Thus we now know that the small size of serranids seen in the 700-year Moturakau sequence is not the result of resource depression at some earlier point in time but rather is a characteristic of the species that was targeted. The results are also significant in that we can now speak with some assurance about the specific habitat and food preferences, behaviors, spawning patterns, and maturation rates of the archaeologically recovered serranid representatives. Knowing that *E. merra* is the main serranid in the bone assemblage has eliminated much potential variation in prey attributes.

DISCUSSION AND CONCLUSIONS

The Aitutaki archaeofaunas provide a particularly useful data set for a consideration of long-term trends in traditional fisheries. They are relatively large, from multiple localities, were processed with fine screens, and derive from well-dated and stratified contexts. Analysis of the fish fauna, and related material culture,

indicate changes in technologies, prey composition, habitat use, and the relative importance of fishing over time. Resolving the causal factors that underlie these trends has been more difficult.

As resource depression has been widely documented by several recent studies (Broughton 1999; Butler 2001; Nagaoka 2000), the potential for this condition was explored with the Aitutaki materials. Application of the resource depression model (Broughton 1999) and derivative indices suggest that over-harvesting may have indeed occurred at the mainland site of Ureia (AIT-10). Over its 1000-year period of occupation large-bodied inshore fish decline, while minor increases in offshore fish suggest that later in time people were traveling further afield to secure their catches. In contrast, the assemblages from Moturakau rockshelter (MR-1), also occupied over a relatively long time period, are not consistent with expectations of the resource depression model. Here, contrary to expectations, large-bodied inshore taxa become *more* abundant over time. Thus while resource depression might account for changing patterns of fishing at Ureia, it cannot be accommodated by the Moturakau data.

Other patterns evident at Moturakau include a striking loss of shell fishhooks, along with more subtle declines in offshore fish such as the snappers and trevallies. The timing of these two trends led to the interpretation that the shell hooks were used largely for capturing larger fish from offshore habitats, although the diversity of forms suggests either multiple hook functions or a great deal of experimentation. Could the loss of pearl shell as a raw material explain declines in offshore fishing? The brief period of experimentation with turban shell hints that pearl shell losses could have had an important impact. Problematically, however, initially it was not clear how important offshore fishing had ever been. In an effort to better understand changing assemblage composition, and by extension patterns of habitat exploitation, mtDNA has recently been explored as a fine-grained identification tool. Its application to serranid remains demonstrates that a single small species dominates the assemblage. Over time there is little evidence for prey-switching and apparently this little fish was a key food source for the people of Aitutaki throughout the period of human settlement. The mtDNA work further resolves the question of serranid habitat placement and allows us to conclude that inshore fishing predominated throughout the settlement period. Moreover, while the Moturakau assemblages reveal a contraction in the sphere of fishing, a pattern that could relate to technological change, the question of why there were island-wide declines in fishing remains unresolved.

The foregoing analyses help to explain the particular patterns at two quite different kinds of sites, the relatively permanent habitation site of Ureia on the mainland, where over-harvesting occurred, and the special purpose site on the offshore islet of Moturakau where shifts in habitat focus may have been pushed along by technological change. Allen (1992*b*) previously argued that, in cost-benefit terms, fishing became increasingly "expensive" over the course of the Aitutaki sequence. The above discussion demonstrates two ways in which fishing costs increased. However, there may have been others. One "cost" that remains unexplored is that of developing and protecting agronomic resources (both gardens and animal domesticates) under what were probably conditions of increasingly finite land and an expanding human population. In this context, offshore fishing in particular would have become increasingly expensive and risky, as well

as requiring expensive technology (sea-worthy canoes and large, strong fishhooks). Notably, fishing strategies used at Western contact were largely inshore focused. They included nets and specially constructed stone fish weirs that were usually less specific in their targets and often captured taxa lower on the food chain.

One approach with the potential to monitor shifts in the agroeconomy (in the absence of field data) is stable isotope analyses. Although poorly developed in the Pacific (but see Leach et al. 1996), stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) have been useful elsewhere for informing on the origins (terrestrial vs. marine) and trophic level of dietary protein (e.g., Cannon 1999; Richards and Hedges 1998). Doctoral student Jacqui Craig of the University of Auckland is currently analyzing pig and dog bone samples from the Aitutaki assemblages with the aim of tracking changes in their dietary protein (Craig 2001). Cannon (1999) has previously demonstrated some success with using dog remains to assess dietary variability in a coastal setting. We aim to extend the method to pig as well. In the Pacific, pig and dog often had diets similar to those of their human captors, and at least in the case of pig the animals have metabolic pathways that are similar to humans (Council 1988). Our expectation is that these two independent data sets (and human materials, should permissions be given) will corroborate patterns indicated by the faunal assemblages, namely a decline in fishing. Should declines in marine protein be demonstrated then we can eliminate from further consideration other potential causes of fish bone declines, as for example changes in discard patterns or human population loss (e.g., Butler 2000). Most importantly, we will have a clear signal that there were fundamental alterations to the agroeconomy, which probably affected not only fishing but also other areas of society.

The changes in fishing seen on Aitutaki are hinted at elsewhere in the central Polynesian region, at least where there are assemblages of sufficient size and temporal duration. Allen et al. (2001), for example, document similar trends in a much smaller assemblage from a single locality on Rotuma. Contractions in the sphere of fishing have been argued for the Marquesas as well (Dye 1990; Leach et al. 1997; Rolett 1998). The Aitutaki case illustrates a range of approaches that may prove useful in evaluating these and other changes in Pacific island subsistence economies, and in time may illuminate critical linkages between diverse social processes.

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ABSTRACT

There is growing evidence that patterns of marine fisheries on some Pacific islands underwent significant changes over the period of human occupation. One such island is Aitutaki in the Southern Cook Islands. Over the millennia of human occupation, there were shifts in habitat use, changes in targeted prey, and the abandonment of some fishing technologies. However, the most striking trend was an apparent decline in fishing altogether. This paper brings together several lines of evidence in an effort to understand why fishing became less important on this small Polynesian "almost-atoll." The possibility of over-harvesting or resource depression is considered. Resource depression could have been a factor at one mainland locality, where occupations were at least semipermanent, but was apparently not involved in declines at an offshore islet site where occupations were short term but intensive. However, fishing on the offshore islet, and deeper water fishing in general, may have been adversely affected by the loss of a key raw material traditionally used for fishhooks, namely pearlshell *(Pinctada margaritifera).* Further consideration of the offshore islet assemblages is assisted by mtDNA analyses, which have allowed for species level determinations within a key family, the Serranidae. Considering the suite of changes as a whole, the costs of fishing apparently increased significantly over the 1000-year period of occupation. What is less certain is the potential role that terrestrial components (i.e., agriculture and animal husbandry) of subsistence played in fishing declines. Stable isotope studies, now underway, may further elucidate the relationships between marine and terrestrial components of subsistence. KEYWORDS: Polynesian fisheries, Cook Islands prehistory, marine economies, zooarchaeology, mtDNA analyses, fishhooks, resource depression.